Use in Mining

This document provides a general overview of the use of cyanide in the gold recovery process, and is not intended to be a technical reference on the use of cyanide to recover gold.

Introduction

Gold typically occurs at very low concentrations in ores - less than 10 g/t or 0.001% (mass basis). At these concentrations the use of aqueous chemical (hydrometallurgical) extraction processes is the only economically viable method of extracting the gold from the ore. Typical hydrometallurgical gold recovery involves a leaching step during which the gold is dissolved in an aqueous medium, followed by the separation of the gold bearing solution from the residues, or adsorption of the gold onto activated carbon. After elution from the activated carbon the gold is further concentrated by precipitation or electrodeposition.

Gold is one of the noble metals and as such it is not soluble in water. A complexant, such as cyanide, which stabilizes the gold species in solution, and an oxidant such as oxygen are required to dissolve gold. The amount of cyanide in solution required for dissolution may be as low as 350 mg/l or 0.035% (as 100% NaCN).

Alternative complexing agents for gold, such as chloride, bromide, thiourea, and thiosulfate form less stable complexes and thus require more aggressive conditions and oxidants to dissolve the gold. These reagents present risks to health and the environment, and are more expensive. This explains the dominance of cyanide as the primary reagent for the leaching of gold from ores since its introduction in the later part of the 19th century.

Manufacture, Transport and Storage of Cyanide

Approximately 1.1 million metric tons of hydrogen cyanide are produced annually worldwide, with approximately 6% used to produce cyanide reagents for gold processing. The remaining 94% is used in industrial applications including production of plastics, adhesives, fire retardants, cosmetics, pharmaceuticals, food processing and as an anti-caking additive for table and road salts.

Cyanide is manufactured and distributed for use in gold mining industries in a variety of physical and chemical forms, including solid briquettes, flake cyanide and liquid cyanide. Sodium cyanide is supplied as either briquettes or liquid, while calcium cyanide is supplied in flake form and also in liquid form. The strength of bulk cyanide reagents vary from 98% for sodium cyanide briquettes, 44-50% for flake calcium cyanide, 28-33% for liquid sodium cyanide and 15-18% for liquid calcium cyanide.

The product strength is quoted on a molar basis as either sodium or calcium cyanide. The form of cyanide reagent chosen for use typically depends on availability,distance from the source and cost. Where liquid cyanide is used, it is transported to the mine by tanker truck or rail car and is off-loaded into a storage tank. The truck or rail car may have a single or double walled tank, and the location and design of the discharge equipment varies by vehicle. Solid briquette or flake cyanide is transported to the mine in drums, plastic bags, boxes, returnable bins and ISO-containers. Depending on how the reagent is packaged, the mine will design and construct the necessary equipment to safely dissolve the solid cyanide in a high-pH solution. The pH value of cyanide solutions during dissolution must be maintained above pH 12 to avoid the volatilization of hazardous hydrogen cyanide (HCN) gas. The resulting cyanide solution is then pumped to a storage tank prior to introduction into the process.

The cyanide solution is fed from the storage tank into the metallurgical process stream in proportion to the dry mass of solids in the process stream. The feed rate of cyanide is controlled to maintain an optimum cyanide level as demanded by the metallurgy of the ore being treated.

A mine's inventory of bulk cyanide reagent is dictated by the requirements to maintain continuous operations, and to limit the frequency of off-loading events, which are regarded as safety critical events.

Although the forms of cyanide vary, once introduced into the process, the technologies used for gold recovery are the same.

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Ore Preparation

Preparation of the ore is necessary so that it can be presented to the aqueous cyanide solution in a form that will ensure the optimal economic recovery of the gold. The first step in ore preparation is crushing and grinding, which reduces the particle size of the ore and liberates the gold for recovery.

Ore that contains free gold may not yield a sufficiently high recovery by sole use of cyanide leaching, due to a very long dissolution time for large gold particles. Such ore may first be subject to a gravity recovery process to recover the free gold before being subjected to cyanide leaching.

Gold bearing ores that contain gold associated with sulfide or carbonaceous minerals require additional treatment, other than size reduction, prior to gold recovery. Gold recovery from sulfide ore is poor because the cyanide preferentially leaches the sulfide minerals rather than the gold, and cyanide is consumed by the formation of thiocyanate. These ores are subject to a concentration processes such as flotation, followed by a secondary process to oxidize the sulfides, thereby limiting their interaction with the cyanide during the gold leach. Carbonaceous minerals adsorb gold once solubilized; oxidizing the ore prior to leaching prevents this. To counter this affect, the leaching process may also be modified by the addition of activated carbon to preferentially adsorb the gold.

Leaching with Aqueous Cyanide Solutions

When gold is leached in an aqueous cyanide solution it forms a gold-cyanide complex by oxidizing with an oxidant such as dissolved oxygen and cyanide complexation. This complex is very stable and the cyanide required is only slightly in excess of the stoichiometric requirement. However, in practice the amount of cyanide used in leach solutions is dictated by the presence of other cyanide consumers, and the need to increase the rate of leaching to acceptable levels.

Typical cyanide concentrations used in practice range from 300 to 500 mg/l (0.03 to 0.05% as NaCN) depending on the mineralogy of the ore. The gold is recovered by means of either heap leaching or agitated pulp leaching.

In heap or dump leaching the ore or agglomerated fine ore is stacked in heaps on a pad lined with an impermeable membrane. Cyanide solution is introduced to the heap by sprinklers or a drip irrigation system. The solution percolates through the heap leaching the gold from the ore, and the resultant gold bearing solution is collected on the impermeable membrane and channeled to storage facilities for further processing. Heap leaching is attractive due to the low capital cost involved, but is a slow process and the gold extraction efficiency is a relatively low 50-75%.

In a conventional milling and agitated leaching circuit, the ore is milled in semi-autogenous ball or rod mills until it is the consistency of powder. The milled ore (slurry) is conveyed to a series of leach tanks. The slurry is agitated in the leach tanks, either mechanically or by means of air injection, to increase the contact of cyanide and oxygen with the gold and enhance the efficiency of the leach process. The cyanide then dissolves gold from the ore and forms a stable gold-cyanide complex.

The use of oxygen or peroxygen compounds instead of air as an oxidant increases the leach rate and decreases cyanide consumption, due to the inactivation of some of the cyanide consuming species present in the slurry.

The pH of the slurry is raised to pH 10-11 using lime, at the head of the leach circuit to ensure that when cyanide is added, toxic hydrogen cyanide gas is not generated and the cyanide is kept in solution to dissolve the gold. The slurry may also be subject to other preconditioning such as pre-oxidation at the head of the circuit before cyanide is added.

Highly activated carbon is used in the dissolved gold recovery process, either by introducing it directly into the CIL (carbon-in-leach) tanks or into separate CIP (carbon-in-pulp) tanks after leaching. The activated carbon adsorbs the dissolved gold from the leach slurry thereby concentrating it onto a smaller mass of solids. The carbon is then separated from the slurry by screening and subjected to further treatment to recover the adsorbed gold.

When carbon is not used to adsorb the dissolved gold in the above-mentioned leach slurry, the gold bearing solution must be separated from the solids components utilizing filtration or thickening units. The resultant solution, referred to as pregnant solution, is subjected to further treatment (other than by carbon absorption) to recover the dissolved gold.

The waste from which the gold was removed by any means is referred to as residue or tailings material. The residue is either dewatered to recover the solution, treated to neutralize or recover cyanide, or is sent directly to the tailing storage facility.

Recovery of Dissolved Gold

Gold is recovered from the solution first using either cementation on zinc powder or concentrating the gold using adsorption on activated carbon, followed by elution and concluding with either cementation with zinc or electrowinning. For efficient cementation, a clear solution prepared by filtration or counter current decantation is required.

The most cost-effective process is to create adsorption of the dissolved gold onto activated carbon, resulting in an easier solid-solid separation based on size. To achieve this the ore particles must typically be smaller than 100 µm while the carbon particles must be larger than 500 µm. Adsorption is achieved by contacting the activated carbon with the agitated pulp. This can be done while the gold is still being leached with the CIL-process, or following leaching with the CIP-process. The CIL-process offers the advantage of countering the adsorption of gold on carbonaceous or shale ore particles, but is more expensive due to less efficient adsorption, increased gold inventory and increased fouling and abrasion of the carbon.

Activated carbon in contact with a pulp containing gold can typically recover more than 99.5% of the gold in the solution in 8 to 24 hours, depending on the reactivity of the carbon, the amount of carbon used and the mixer's efficiency. The loaded carbon is then separated from the pulp by screens that are air or hydrodynamically swept, thus preventing blinding by the near sized carbon particles. The pulp residue is then either thickened to separate the cyanide containing solution for recovery/destruction of the cyanide, or sent directly to the tailings storage facility from which the cyanide containing solution is recycled to the leach plant.

The gold adsorbed on the activated carbon is recovered from the carbon by elution, typically with a hot caustic aqueous cyanide solution. The carbon is then regenerated and returned to the adsorption circuit while the gold is recovered from the eluate using either zinc cementation or electrowinning. If it contains significant amounts of base metals, the gold concentrate is then either calcined or directly smelted and refined to gold bullion that typically contains about 70 - 90% gold. The bullion is then further refined to either 99.99% or 99.999% fineness using chlorination, smelting and electro-refining. High purity gold is taken directly from activated carbon eluates, using recently developed processes that utilize solvent extraction to produce intensive leaching of gravity concentrates.

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